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Arcara, Giorgio ; Franzon, Francesca ; Gastaldon, Simone ; Brotto, Silvia ; Semenza, Carlo ; Peressotti, Francesca ; Zanini, Chiara

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One can be some but some cannot be one:
ERP correlates of numerosity incongruence are different for singular and plural

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Abstract

Humans can communicate information on numerosity by means of number words (e.g. *one hundred, a couple*), but also through Number morphology (e.g. through the singular vs. the plural forms of a noun). Agreement violations involving Number morphology (e.g. **one apples*) are well known to elicit specific ERP components such as the Left Anterior Negativity (LAN); yet, the relationship between a morphological Number value (e.g. singular vs. plural) and its referential numerosity has been scantly considered in the literature. Moreover, even if agreement violations have been proved very useful, they do not typically characterise the everyday language usage, thus narrowing the scope of the results.

In this study we investigated Number morphology from a different perspective, by focusing on the ERP correlates of congruence and incongruence between a depicted numerosity and noun phrases. To this aim we designed a picture–phrase matching paradigm in Italian. In each trial, a picture depicting one or four objects was followed by a grammatically well-formed phrase made up of a quantifier and a content noun inflected either in the singular or in the plural. When analysing ERP time-locked to the content noun, plural phrases after pictures presenting one object elicited a larger negativity, similar to a LAN effect. No significant congruence effect was found in the case of the phrases whose morphological Number value conveyed a numerosity of one. Our results suggest that incongruence elicits a negativity (LAN-like) independently from the grammaticality of the utterances and irrespective the P600 component; 2) the reference to a numerosity can be partially encoded in an incremental way when processing Number morphology; and, most importantly, 3) the processing of the morphological Number value of plural is different from that of singular as the former shows a narrower interpretability than the latter.

Keywords: Number morphology, ERP, LAN, singular, plural.

1. Introduction

The first thing that typically comes to mind when speaking of numerical abilities is probably performing calculation. We are so accustomed to counting and estimating that we hardly ever pay attention to how often we resort to basic numerical abilities in everyday life. Even our linguistic choices would not be effective without basic numerical reasoning; indeed, the pertinence of a singular form (e.g. *apple*) instead of a plural form (e.g. *apples*) strictly depends on the numerosity of the relevant referent. A great body of the literature has claimed that numerical reasoning stems from a subset of non-verbal numerical cognitive and phylogenetically ancient skills with which human and non-human animal species are endowed soon after birth in order to behave successfully (Cantlon & Brannon, 2007; Dehaene, 2011; Rugani, Vallortigara, Priftis, & Regolin, 2015; Spelke, 2000; Starr, Libertus, & Brannon, 2013). Numerical abilities as well as abilities concerning naïve physics, space and motion have been argued to be part of the core knowledge systems which would allow human and non-human animal species to represent the most important aspects of their environment (Carey, 2009; Spelke, 2000). Recently, it has been proposed that humans have also developed enhanced communicative systems, i.e. languages, to share information coming from mental experiences, and from the core knowledge systems in particular (e.g. Corballis, 2017). Indeed, if core knowledge information is biologically fundamental, its prompt communication must be in some way advantageous. Interestingly enough, core knowledge information would be so relevant to shape the core structure of human languages (Bickel, Witzlack-Makarevich, Choudhary, Schlesewsky, & Bornkessel-Schlesewsky, 2015; Christiansen & Chater, 2008; Franzon, Zanini, & Rugani, 2018; Strickland, 2017). To what extent is this true for numerical knowledge? How does numerical knowledge shape language grammars and influence linguistic processing?

The great majority of the studies investigating the relationship between numerical knowledge and its encoding into language have taken into consideration the lexical level, mainly focussed on quantifiers and number words (e.g. Butterworth et al., 1999; Carey, 2004; Clark & Grossman, 2007; Gelman & Gallistel, 2004; Gordon, 2004; Lipton & Spelke, 2003; Ochtrup et al., 2013; Rath et al., 2015; Salillas, Barraza, & Carreiras, 2015; Troiani, Peelle, Clark, & Grossman, 2009). It has been shown that speakers of languages without number words do master non-verbal numerical skills (e.g. Butterworth, Reeve, Reynolds, & Lloyd, 2008; Pica, Lemer, Izard, & Dehaene, 2004), being these latter independent from the verbal ones, and that number words are dissociated from other lexical categories (Bencini et al., 2011; e.g. Semenza et al., 2007). However, the information about numerosity can be expressed into the language without relying on number words by means of Number morphology, which systematically encodes it into different signs (e.g. *cat* vs. *cats* in English). It has been estimated that at least the 90.8% of the languages reported in the WALS (Dryer & Haspelmath, 2013) have a grammatical device to encode nominal plurality (Dryer, 2013). The grammaticalised elements conveying the possible morphological Number values (often singular and plural) are mostly phonologically short (e.g. *–s* in English for the plural) and mandatorily expressed (i.e. all nouns or all the nouns belonging to a certain category such as animate or countable nouns must be inflected for Number; among others see Dressler, 1989). In other words, Number morphology is one of the most exploited devices throughout human languages to readily communicate basic information about the numerosity of the referential world. These peculiarities of Number morphology make intriguing the investigation of the processing related to it. For example, children who speak languages displaying morphological Number values (e.g. singular, plural, dual) have been shown to acquire the relevant number words (such as *one* or *two*) earlier than children who speak languages without morphological Number values (Almoammer et al., 2013; Marušič et al., 2016; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007). A study conducted on German by Roettger and Domahs (2015) reported an effect similar to SNARC (spatial-numerical association of response codes) related to morphological Number in performing a series of behavioural tasks. The authors found that words inflected in the singular had a relative left-hand advantage and words in the plural a relative right-hand advantage. This finding seems to point to the fact that quantity representation is accessed while processing morphological Number. In a fMRI study on adult Spanish speakers, Carreiras and colleagues (2010) found increased activation of the right superior parietal gyrus and of the right intraparietal sulcus only in conditions tackling the morphological Number, but not in conditions dealing with other morphological features such as Gender; significantly, the activation of these areas was found to be associated with non-verbal numerosity processing (Butterworth et al., 1999; Dehaene, Piazza, Pinel, & Cohen, 2003; Pinel, Piazza, Le Bihan, & Dehaene, 2004).

Yet, Number morphology *per se* and its link with numerosity have been scantly considered in experimental studies, especially when compared with the long-standing tradition of works investigating the mere functional facet of Number as a feature to perform agreement (*the cat meows* vs. **the cat meow*). As observed by Molinaro, Barber and Carreiras (2011) in their review on ERP findings as for agreement processing, “although a large number of papers have been devoted to Number agreement, no study until now has focused on the qualitative distinction between the values that express Number” (Molinaro et al., 2011: 926). Actually, since pioneer ERP studies, Number agreement has been widely explored (e.g. Friederici, 1995; Hagoort, Brown, & Groothusen, 1993; Kutas & Hillyard, 1983; Osterhout & Mobley, 1995). Typically, participants were asked to passively read or listen to grammatical and ungrammatical sentences (or phrases); as an alternative, they were asked to express grammaticality judgments or answer comprehension questions after having read/heard each sentence (or phrase). In a seminal study on English, Kutas and Hillyard (1983) contrasted syntactic and semantic violations in a comprehension task. They found that subject-verb Number agreement violations elicited a negative peak (Left Anterior Negativity, LAN) in electrical brain activity between 200 and 500 ms in anterior zones after stimulus presentation. In a study on Dutch using a passive reading task, Hagoort et al. (1993) reported a P600 effect, i.e. a posterior positive peak occurring 600 ms after stimulus presentation, in response to the same type of agreement violations.

The LAN effect alone, the P600 effect alone or the LAN-P600 pattern have been reported in most of the later studies (e.g. Barber & Carreiras, 2003, 2005; Barber, Salillas, & Carreiras, 2004; De Vincenzi et al., 2003; Kaan, 2002; Silva-Pereyra & Carreiras, 2007), even in studies involving other morphological features such as Gender (e.g. Caffarra, Janssen, & Barber, 2014), and their presence and modulation may depend on the type of the stimuli involved. For example, Barber and Carreiras (2005) found that Number violations in adjective-noun agreement elicited an N400 effect (which is typically found in tasks involving semantic violations) while an additional LAN effect was triggered in the determiner-noun context; in addition, when the same violations were presented in a sentence context, they resulted in a LAN-P600 pattern. Interestingly enough, it has been shown that the LAN component is generally not triggered when morphological Number values are not conveyed at the morpho-phonological level: in a study on Italian, Molinaro, Vespignani, Zamparelli and Job (2011) recorded the LAN in the subject-verb disagreement condition where the numerosity of the subject was morphologically specified (as in **I ragazzi.PL corre.SG* ‘the boys runs’), but not where it was only syntactically driven (as in **Il ragazzo.SG e la ragazza.SG corre.SG* ‘The boy and the girl runs’). The LAN component has not been found also when the two elements involved in the Number agreement relation respectively belong to two different clauses; in fact, it seems that the intra-sentence domain is mostly relevant to morphological Number cues (e.g. Kaan, Harris, Gibson, & Holcomb, 2000; Kaan & Swaab, 2003; Münte, Szentkuti, Wieringa, Matzke, & Johannes, 1997).

The consistency in findings across most of the studies had led to interpret the LAN component as an index of difficulties in the early stages of the syntactic processing focused on morphological cues (e.g. Friederici, 1995, 2002; 2011, Hagoort, 2005; Ullman, 2001). Such view is not fully embraced by many scholars who instead explained the LAN component as an index of working memory operations generally involved in language processing (Fiebach, Schlesewsky, & Friederici, 2001; King & Kutas, 1995; Kluender & Kutas, 1993). More recently and more generally, the interpretation of the LAN and the P600 components as indexes of processing of high-level linguistic features has been criticised. For example, the P600 has been traditionally linked to a later integration of the processed constituent at the sentence level (e.g. Barber, Salillas, & Carreiras, 2004; Kaan, Harris, Gibson, & Holcomb, 2000; Kaan & Swaab, 2003); yet, such view has been increasingly challenged by researchers claiming that P600 effects may correlate with violations other than purely syntactic and linguistic ones since the P600 might be related to the P300 family and to general cognitive processing as context-updating (e.g. Bornkessel-Schlesewsky & Schlesewsky, 2008; Sassenhagen, Schlesewsky, & Bornkessel-Schlesewsky, 2014; see also Van Petten & Luka, 2012). Similarly, the LAN component has been interpreted as an illusion effect resulting from individual differences in brain responses between N400 and P600 effects rather than an autonomous morpho-syntactic component (Tanner, 2015; Tanner & Van Hell, 2014). Molinaro and colleagues (2015; 2011) do not agree with such view claiming for an independent LAN component detectable event without the P600. The authors linked the reliability of the LAN effect to the type of the morpho-syntactic structure at issue: the more a morpho-syntactic mismatch is unambiguously detectable as ungrammatical, the higher the probability to elicit a LAN effect. In this sense, the LAN could be considered an index of morpho-syntactic expectation in addition to an index of difficulty in integrating morpho-syntactic anomalies in the context.

The fact that almost all the ERP studies on morphological Number have exploited violation paradigms does not allow to disentangle between these two interpretations of the LAN effect. Can the LAN be found without resorting to violation paradigms and interpreted as an index of morpho-syntactic expectation independently from the detection of grammatical anomalies? In this regard, it is worth noticing that another ERP component, the N400, usually linked to the detection of semantic anomalies, is modulated also by contextually generated expectancies irrespectively from purely agreement or semantic violations (e.g. DeLong, Urbach, & Kutas, 2005). Anticipatory processing was found in many cognitive domains, and the grammars of human languages do not represent an exception to this. For example, it is well known that features involved in agreement rules, among which morphological Number, are systematically used to predict upcoming linguistic and/or visual materials as reported in several eye-tracking studies (Altmann & Kamide, 2007; for a review see Huettig, Rommers, & Meyer, 2011). And yet the relationship between morphological Number values, the denoted numerosity and their role in anticipatory processing is comparatively an under-researched topic in the ERP field.

1.1 The present study

The present ERP study intends to help filling the gap in the literature on morphological Number by investigating the time course of the processing of singular and plural, without exploiting a grammatical violation paradigm. Indeed, the goal is to investigate the congruence between morphological Number values (i.e., singular/plural) and the respective denoted numerosity (i.e. figure of one object or of several objects) rather than a grammatical relational property such as Number agreement. To this aim, we designed a paradigm in which a picture representing one or more objects was followed by a noun phrase inflected in the singular or in the plural. Participants had to judge whether the noun phrase appropriately described the preceding picture, namely whether it was congruent or not.

The task was administered to Italian adult speakers as Italian language mostly displays a phonologically transparent Number morphology. Most importantly, Italian has two quantification expressions, *alcuni* ‘some’ + *noun.PL* and *qualche* ‘some’ + *noun.SG*, both of which refer to a plural numerosity; yet, nouns agree in the plural with *alcuni*, but in the singular with *qualche*. This peculiarity of Italian helps to disentangle effects due to the morpho-phonological form of a morphological Number value from effects due to its referential meaning. Finally, the long tradition in electrophysiological studies on Italian Number (dis)agreement allows comparability between the previous and the present results as far as the interpretation of the ERP components is concerned.

We hypothesised that ERP responses were more prone to being modulated by the referential meaning effects than morpho-phonological ones. Given previous evidence on partial incremental processing of language (Urbach & Kutas, 2010), we expected to be able to elicit more negative LAN or N400 components in the incongruent condition as compared to the congruent one. As this is the first study to our knowledge, to perform this kind of investigation, we did not have specific expectations on the difference between singular and plural.

2. Method

2.1 Participants

Twenty-seven young adult native speakers of Italian took part to the study as volunteers. One participant was excluded from the analysis because of a misunderstanding of the task instructions, discovered in a de-briefing after the experiment. Thus, the final analyses included a total of twenty-six participants (females = 17; mean age = 24.5; min age = 20; max age = 32; SD = 2.98). All participants were right-handed, had normal or correct-to-normal vision, and had no reported history of reading or learning disorders. All participants signed a written informed consent before taking part to the study. The experiment was approved by the Local Ethics Committee.

2.2 Procedure

Participants were tested in a dimly lit, quiet room. They were asked to complete a picture-phrase matching task, performed on a computer screen. The task (an adaptation from Gastaldon et al., 2016), was delivered with the E-prime software (Psychology Software Tools, 1999, Pittsburgh, PA). Each trial consisted of the following sequence: first, a fixation cross appeared in the centre of the screen (1000 ms); afterwards, a picture showed up (1000 ms) followed by a short blank screen for 200 ms and then by two words. The first word was displayed for 300 ms, followed by a blank screen (200 ms), and the second word was displayed for 300 ms. The words were followed by another blank screen with a random duration between 1000 or 1500 ms, after which two response words (True and False) appeared at the right and at the left side of the screen. The participants were asked to respond whether the two-words sequence described appropriately the preceding picture, without any time pressure. The position of the response words (i.e. True/False) as well as that of the corresponding response keys were always the same for each participant, but counterbalanced across participants. The trial procedure is illustrated in Figure 1. All stimuli subtended at most 5 degrees on the horizontal plane, to avoid excessive eye movements. Five practice trials were administered before the beginning of the experiment to familiarise with the task. The overall task lasted about 45 minutes. The task included twelve breaks, and so the participants had the opportunity to rest every 5 minutes. Prior to the beginning of the task, we also recorded a 5-minute session of resting-state, not further analysed in the present study.

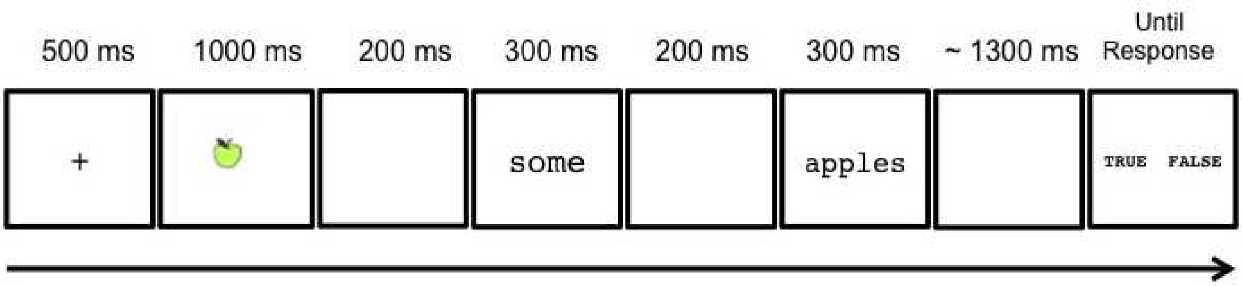


Figure 1. **Task Design**. The picture shows the design of the task employed. All trials followed the depicted sequence. After a fixation cross a picture was displayed, followed by a two-word phrases presented in a word-by-word fashion. Participants had to respond if the phrases corresponded to the presented picture by pressing two buttons associated with TRUE/FALSE response (FALSE, in the depicted example). There was no time pressure for the response.

2.3. Materials

The linguistic stimuli of the experiment consisted in phrases made up of quantifier-noun pairs. We decided to present nouns modified by a quantifier rather than bare nouns to control for the interpretation of the morphological Number values. In fact, according to many theoretical linguistic accounts, in very particular cases singular and plural markings can alternately convey a reading of general Number, that is a Number value that does not refer to any numerosity with respect to a countable entity (Corbett, 2000). In Italian, the general Number can surface syncretically to the form of singular as in the expression *qualche gatto* 'some cats; lit. some cat.SG' where the morpheme *–o* of the noun *gatto* does not mean "one", but the plural meaning is conveyed by the quantifier *qualche* (among others, Acquaviva, 2013; Franzon, Zanini, & Rugani, 2018; Zamparelli, 2008). Thus, we selected three quantifiers:

- *one+noun.SG*: the nouns were inflected in the singular and linked with a numerosity of one since they were preceded by the numeral quantifier 'one' (e.g. *una mela* 'one apple'). This latter can surface in Italian with a masculine (*un/uno*) or feminine (*una*) singular marking.
- *some+noun.PL*: the nouns were inflected in the plural and linked with a numerosity greater than one denoting few entities since they were preceded by the quantifier 'some' (e.g. *alcune mele* 'some apples'). This latter can surface in Italian with a masculine (*alcuni*) or feminine (*alcune*) plural marking.
- *some°+noun.SG*: the nouns bore a marking which is singular from a morpho-phonological point of view. Yet, they were preceded by the quantifier *qualche*, meaning 'some', and thus their morpho-phonological marking of singular must be interpreted as a general Number linked to an interpretation of plurality (e.g. *qualche mela* 'some apples', lit. 'some apple'). It is worth noticing here that this quantification expression is perfectly grammatical in Italian and that both *alcuni/e* and *qualche* refer to a plural numerosity with a paucal reading (e.g. Zamparelli, 2008). We decided to add this condition besides the previous ones since all together are useful to disentangle effects due to the morpho-phonological form of a Number value (singular vs. plural) from effects due to the semantic feature linked with the Number value in a given phrase context (singularity vs. plurality).

In the rest of the manuscript we refer to the variable associated with the three levels one+noun.SG, some+noun.PL, and some°+noun.SG as *Semantic feature of the morphological Number*[1] (henceforth: *Semantic F-Number*). Importantly, with this label we classify the conditions according to the number value at the phrase level (i.e., the combination of quantifier and content word), and not a single-word level.

The stimuli were created to be matched, as much as possible, for length and frequency. We took into account, in particular, the orthographic length of the content nouns (e.g. the length of *mela*, 'apple'), and the orthographic length and the frequency of the whole phrases (e.g. *una mela* 'one apple'). Length was calculated as number of graphemes (i.e. letters), whereas frequency was calculated as log-transformed frequency, collected from the itWaC corpus (Baroni, Bernardini, Ferraresi, & Zanchetta, 2009). Considering the content nouns, stimuli were matched for length and frequency across all conditions. Considering the phrases (quantifier plus content word), the condition with *one+noun.SG* was always more frequent than the conditions *some+noun.PL* and *some°+noun.SG*. It was not possible to match on the phrase frequency given the intrinsic properties of distribution of these quantifiers in Italian. They were also unbalanced in terms of phrase length as the quantifier *uno/a* 'one' was always two or three letters long, the quantifier *qualche* 'some°' was always seven letters long, and the quantifier *alcuni/e* 'some' was always six letters long. In each phrase, all content nouns referred to concrete, countable, and non-animate objects. We selected two pictures for each noun, representing either one single object or four instances of that object (we choose four objects as this is a numerosity possibly associated with a reference of paucal in language grammars; see, among others, Corbett, 2000). The drawings in the pictures were arranged to avoid any kind of effect due to structural composition. In particular, in the picture representing one single object the drawing was decentralised to minimise possible effects due to the less space occupied by the object in comparison with that occupied by four objects. In the pictures representing four objects the drawings were arranged in pseudo-random positions.

Each picture-to-phrase matching could be congruent (e.g. a picture of four apples followed by the phrase 'some apples') or incongruent. The mismatches concerned either the numerosity of the objects (e.g. a picture of one apple followed by the phrase 'some apples') or the referential objects themselves (e.g. a picture of one orange followed by the phrase 'one sponge'). The inclusion of a condition with a mismatch between the depicted object and the last word (i.e. the noun) was crucial to ensure that participants processed the entire phrase and not only the first word. To avoid excessive repetition of stimuli during the task we used separate lists of stimuli for the contrast on the denoted numerosity and for the contrast on the denoted referents. We did not include a condition with both types of incongruence. At the end each combination of experimental variables included 30 stimuli for a total of 360 experimental stimuli.

Summarising, in creating the stimuli the following variables were taken into account**:** *Contrast* (denoted and depicted numerosity vs. denoted and depicted objects); *Semantic F-Number*

[1] In Italian, it is not always possible to interpret a morphological Number value independently from the context (for example, the Number value of singular can convey both singularity or mass interpretation and only the pragmatic or syntactic context disambiguate from these two meanings (della pizza "some pizza" vs. una pizza "a pizza"). In the experimental conditions included we constrained the interpretation of the morphological values in the experimental design both in the prototypical cases (one+noun.SG, some+noun.PL) and in the non-prototypical one (some°+noun.SG). Importantly, the contrast does not tackle the referential level, but the morphological (linguistic internal) level, as it concerns the link between the form of a morpheme and its meaning. For this reason, we labelled the condition "Semantic feature of the morphological Number".

(*one+noun.SG* vs. *some+noun.PL* vs. *some*°+ *noun.SG*), *Congruence* (congruent trial vs. incongruent trial). The number of stimuli and the combinations are summarized in Table 1, while properties on the psycholinguistic variables taken into account are reported in Table 2

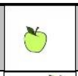
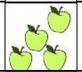
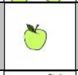
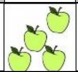
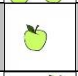
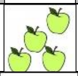
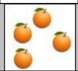
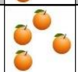
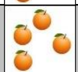
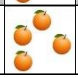
Condition	*Picture numerosity*	*Presented phrase*	*Phrase example*	Numerosity at phrase level /congruence	Numerosity at morphological level/congruence	N° of Stimuli
Depicted Numerosity		*one+noun.SG*	*“one apple”* (una mela)	SG / True	SG / True	30
		*one+noun.SG*	*“one apple”* (una mela)	SG / False	SG / False	30
		*some+noun.PL*	*“Some apples”* (alcune mele)	PL / False	PL / False	30
		*some+noun.PL*	*“Some apples”* (alcune mele)	PL / True	PL / True	30
		*Some°+noun.SG*	*“Some° apple” (qualche mela)*	PL / False	SG / True	30
		*Some°+noun.SG*	*“Some° apple”* (qualche mela)	PL / True	SG / False	30
Depicted Object		*one+noun.SG*	*“one orange”* (una arancia)	SG / True	SG /True	30
		*one+noun.SG*	*“one sponge”* (una spugna)	SG / True	SG / True	30
		*some+noun.PL*	*“some oranges”* (alcune arance)	PL / True	PL / True	30
		*some+noun.PL*	*“some sponges”* (alcune spugne)	PL / True	PL / True	30
		*Some°+noun.SG*	*“some° orange”* (qualche arancia)	PL / True	PL / False	30
		*Some°+noun.SG*	*“some° sponge”* (qualche spugna)	PL / True	PL / False	30

Table 1. Experimental stimuli. The table reports the experimental stimuli. The first column reports the task contrast (on Depicted Numerosity or on Depicted Object); the second column reports an example of the picture displayed. The third column the type of quantifier (and its label throughout the manuscript). The fourth column reports an example of the object noun. The fifth column reports the congruence between the Picture and the quantifier-content word pairs (that was also the response required by the participant). The sixth column reports an example of a trial, that included a whole combination of variable levels. Each trial consisted of a picture followed by two words (Italian original version enclosed in parentheses). The seventh column report reports the total number of stimuli included for each combination of variable levels.

PHRASE- LENGTH									
	mean	sd	median	min	max	skewness	kurtosis	Q1	Q3
Numerosity contrast - some+noun.PL	13.13	1.21	13	11	16	0.76	0.04	12	14
Numerosity contrast - some°+noun.SG	14.1	1.17	14	12	17	0.55	-0.41	13	15
Numerosity contrast - one+noun.SG	9.7	1.2	9	8	12	0.46	-0.82	9	11
Object contrast - some+noun.PL	12.85	1.05	13	11	15	-0.05	-0.95	12	14
Object contrast - some°+noun.SG	13.77	1.06	14	12	16	0.13	-0.7	13	14.25
Object contrast - one+noun.SG	9.53	1.08	10	7	11	-0.6	-0.07	9	10

CONTENT WORD - LENGTH									
Numerosity contrast - some+noun.PL	mean	sd	median	min	max	skewness	kurthosis	Q1	Q3
Numerosity contrast - some°+noun.SG	6.13	1.21	6	4	9	0.76	0.04	5	7
Numerosity contrast - one+noun.SG	6.1	1.17	6	4	9	0.55	-0.41	5	7
Object contrast - some+noun.PL	6.1	1.17	6	4	9	0.55	-0.41	5	7
Object contrast - some°+noun.SG	5.85	1.05	6	4	8	-0.05	-0.95	5	7
Object contrast - one+noun.SG	5.77	1.06	6	4	8	0.13	-0.7	5	6.25
	5.93	0.99	6	4	8	-0.28	-0.84	5	7

PHRASE - FREQUENCY									
Numerosity contrast - some+noun.PL	mean	sd	median	min	max	skewness	kurtosis	Q1	Q3
Numerosity contrast - some°+noun.SG	2.97	1.35	2.92	1.1	7.07	0.97	0.9	1.79	3.76
Numerosity contrast - one+noun.SG	3.34	1.34	3.11	1.1	6.94	0.76	0.44	2.4	3.93
Object contrast - some+noun.PL	6.66	1.97	6.94	0	10.88	-1.27	3	6.06	7.76
Object contrast - some°+noun.SG	2.79	1.46	2.77	0	5.39	0.15	-1.05	1.55	3.62
Object contrast - one+noun.SG	2.81	1.38	3.22	0	5.13	-0.6	-0.4	2.05	3.72
	7.3	1.69	7.48	0	9.67	-2.49	8.97	6.85	8.16

CONTENT WORD - FREQUENCY									
Numerosity contrast - some+noun.PL	mean	sd	median	min	max	skewness	kurtosis	Q1	Q3
Numerosity contrast - some°+noun.SG	8.78	0.99	8.71	6.9	11.95	0.78	1.83	8.28	9.13
Numerosity contrast - one+noun.SG	8.99	1.15	8.95	6.93	12.59	0.84	1.45	8.21	9.55
Object contrast - some+noun.PL	8.99	1.15	8.95	6.93	12.59	0.84	1.45	8.21	9.55
Object contrast - some°+noun.SG	8.63	1.24	8.41	6.88	11.12	0.31	-1.04	7.74	9.69
Object contrast - one+noun.SG	9.5	1.2	9.44	7.2	12.13	0.46	-0.52	8.69	10.25

Table 2. Psycholinguistic variables. The table reports the means, standard deviations, median, minimum, maximum, skewness, kurtosis, first quartile and third quartile for the psycholinguistic variables taken into account. Details on statistical comparison between stimuli are reported in Supplemental Data.

2.4 EEG data recording

EEG signal was recorded from 28 active electrodes embedded in an elastic cap, arranged according to the 10/20 system (Brain products, Acticap). Each electrode was referenced on-line to the left earlobe. Three additional electrodes were used to monitor eye movements and blink, with two electrodes placed near the outer corner of the eyes (*external canthi*) and one placed in a pupil centred position, under the left eye. The impedance of each electrode was kept lower than 10 KΩ throughout the recording. The following electrodes were included: Fp1, Fp2, Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, C3, C4, Cz, T7, T8, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, O1, O2, Oz. The EEG signal was amplified by using BrainAmp amplifiers with hardware high-pass of 0.1 and with a sampling rate of 500 Hz.

2.5 EEG data analysis

EEG data were pre-processed with Brainstorm MATLAB toolbox (Tadel et al., 2011, March 2015 version). In the pre-processing phase, first we applied a high-pass filter at 0.5 Hz to the continuous data. Afterwards, we used Independent Component Analysis (ICA) to remove artifacts with well-defined topography: blinks and the power line noise at 50 Hz. From the ICA corrected continuous data, we extracted epochs time-locked to the onset of the first word, ranging from -3000 ms to 2000 ms after stimulus. Trials containing excessive artifacts were rejected in this phase after visual inspection. From these initial epochs, smaller epochs around the first word (the quantifier) and the second word (the content noun) were extracted, with a time window spanning from -500 pre stimulus to 1500 ms post stimulus, baseline corrected to the mean value of 100 ms preceding the stimulus. We calculated separately an average for each condition, including only trials with a correct behavioural response. On these final ERP averages, a low-pass filter at 40 Hz was applied. The mean number of accepted trial for each condition was 94% (mean accepted trials 28.2 out of 30 for condition), with no appreciable differences across conditions (number of accepted trials separate for condition ranged from 93% to 95%). Statistical analysis and graphics were made with R (R core Team, 2016) and with the two R packages *erpR* (Arcara & Petrova, 2017), and *ez* (Lawrence, 2015).

We focused the statistical analysis on the ERPs time-locked to the second word (the content noun). To this aim we conducted two different analyses, ANOVAs on a-priori selected time windows and electrodes, and mass univariate statistics (Groppe, Urbach, & Kutas, 2011) on all electrodes and timepoints.

For ANOVA analyses we selected two time windows and four group of electrodes to investigate the effects, basing our choice on the literature (Molinaro et al., 2015) and prior to any visual inspection of ERP waveforms. We focused on the 350-450 ms windows to investigate the effect of LAN and on the 700-1000 time window to investigate the effect of Late positivities and P600.

To investigate topographical effects, we focused on 12 electrodes grouped in 4 Region of interests (ROI): a left anterior (F3, FC5, FC1) a right anterior (F4, FC6, FC2), a left posterior (CP1, CP5, P3) and right posterior (CP2, CP6, P4). Values for each ROI were calculated as mean amplitude of the electrodes included in the ROI. These ROIs were associated to two variables, *laterality* and *caudality*.

The repeated ANOVAs (separated for the two levels of *contrast* on denoted numerosity and denote objects) condition included four within variables with a 3 × 2 × 2 × 2 design: *Semantic-F Number* with three levels (one + noun.SG vs. some + noun.PL vs. some°+ noun.SG), *Congruence* with two levels (True, False), *caudality* with two levels (anterior, posterior) and *laterality* with two levels (left, right).

When more than two levels of a repeated measure variable were involved, a preliminary Mauchly test for sphericity was performed. If sphericity assumption was not met, Greenhouse-Geisser correction was applied. Effect size for ANOVA effects was calcualted as global eta squared (η_G^2) a more accurate estimate of effect size than traditional η_p^2 in the case of repeated measure design (Bakeman, 2005). Post-hoc contrasts were performed by means of paired t-tests, corrected for multiple comparisons with no Discovery Rate (FDR) correction method (Benjamini & Hochberg, 1995). All post-hocs performed are reported in the Supplemental Data.

We also analysed the data also using a mass univariate approach (Groppe, Urbach, & Kutas, 2011). In this analysis we performed a series of separate t-tests for each time point and each electrode starting from 0 to 1000 ms (in the ERPs time-locked to the noun), separately for each type of contrast (on depicted numerosity or on depicted object) and separately for each *Semantic F-Number* (*one+noun.SG* vs. *some+noun.PL* vs. *some°+ noun.SG*), we investigated the effect of *Congruence* (congruent trial vs. incongruent trial). Within each contrast we corrected for inflated type-1 error associated to the high number of comparisons using FDR correction for time points and electrodes. To be more stringent in our analysis, we also excluded all those effects that lasted less than 50 ms (probably ascribable to noise, rather than to real effects).

The results on the first words (i.e., the quantifiers) were difficult to be compared, as the quantifiers showed intrinsic differences, in length and frequency, that are relevant confounds to the effects of interest. For the sake of transparency and completeness, we used a similar mass univariate approach to analyse the results on the first word, but in a more exploratory fashion (as we did not have specific hypotheses). Detailed results for the first word are reported in the Supplemental Data.

3. Results

3.1. Behavioural analysis

The performance in the task was almost at ceiling in almost all of the subjects. The mean percentage of errors was 0.8% on the total of 360 stimuli (mean number or errors = 2.96, SD = 3.513, range = 0-13). As the performance was almost at ceiling, data on accuracy were not further analysed. As there was no time pressure to give the response, reaction times were not analysed.

As all the participants performed the task with high accuracy, this ensured they understood the task and paid attention to the stimuli that were included in the analysis.

3.2. EEG analysis

ERPs grandaverages time locked to the content word for selected electrodes and topographic plots of the effect in the early time window (350-450), are reported in Figure 2 and 3. Further figures on all electrodes are reported in the Supplemental Data.

In the ANOVA analysis only main effects and interaction involving the experimental variables of interest (*Numerosity* and *Congruence*) are reported. Following standard recommendation of reporting statistic results, only higher order significant results are discussed. Full results for ANOVA, as well as details on all post-hocs are reported in the Supplemental Data.

3.3. ANOVA analysis

3.3.1. Contrast on depicted numerosity, early time window (350-450)

In this analysis we found a significant interaction of *Semantic F-Number* × *congruence* [$F(2,50) = 5.02$, $p = 0.01$, $\eta_G^2 = 0.03$]. Post-hoc contrasts related to this interactions showing that the two conditions linked to a semantic interpretation of plurality (*some°+noun.SG* and *some+noun.PL*) had more negative values with the incongruent picture (i.e., a picture depicting one item) as compared to congruent picture (i.e. picture depicting four items) [corrected *ps* < 0.05]. No significant difference was evidenced when the morphological numerosity was singular (i.e. in the conditions involving *one+noun.SG*), regardless the depicted numerosity in the preceding picture (i.e. regardless of the congruence) [$p = 0.24$]. The values for the singular form were similar to the congruent values in the plural form [ps > 0.05].

The interaction *Semantic F-Number* × *laterality* was also significant [$F(2,50) = 3.83$, $p = 0.03$*], post-hocs showed that in general values were more negative in the left hemisphere than in the right hemisphere. Both in the left and in the right hemispheres, *some+noun.PL* condition has more negative values than *some°+noun.SG*, which in turn more negative values than *one+noun.SG* [all *ps* < 0.05]. However, this difference was less pronounced for the *one+noun.SG* [$p = 0.047$], as compared to the plural [ps < 0.01].

3.3.2. Contrast on depicted numerosity, late time window (700-1000)

This analysis evidenced a significant effect interaction *Semantic F-Number* × *congruence* [$F(2,50) = 7.31$, $p < 0.001$, $\eta_G^2 = 0.04$]. Post-hocs showed that *some°+noun.SG* and *some+noun.PL* had less positive values when preceded by the incongruent picture (i.e. a picture depicting one item) as compared to the congruent picture (i.e. a picture depicting four items) [corrected *ps* < 0.05]. When the semantic feature linked to the Number morpheme was interpretable as singular (i.e. conditions involving *one+noun.SG*), no significant differences related to the congruence of the preceding figure [$p = 0.77$] were observed.

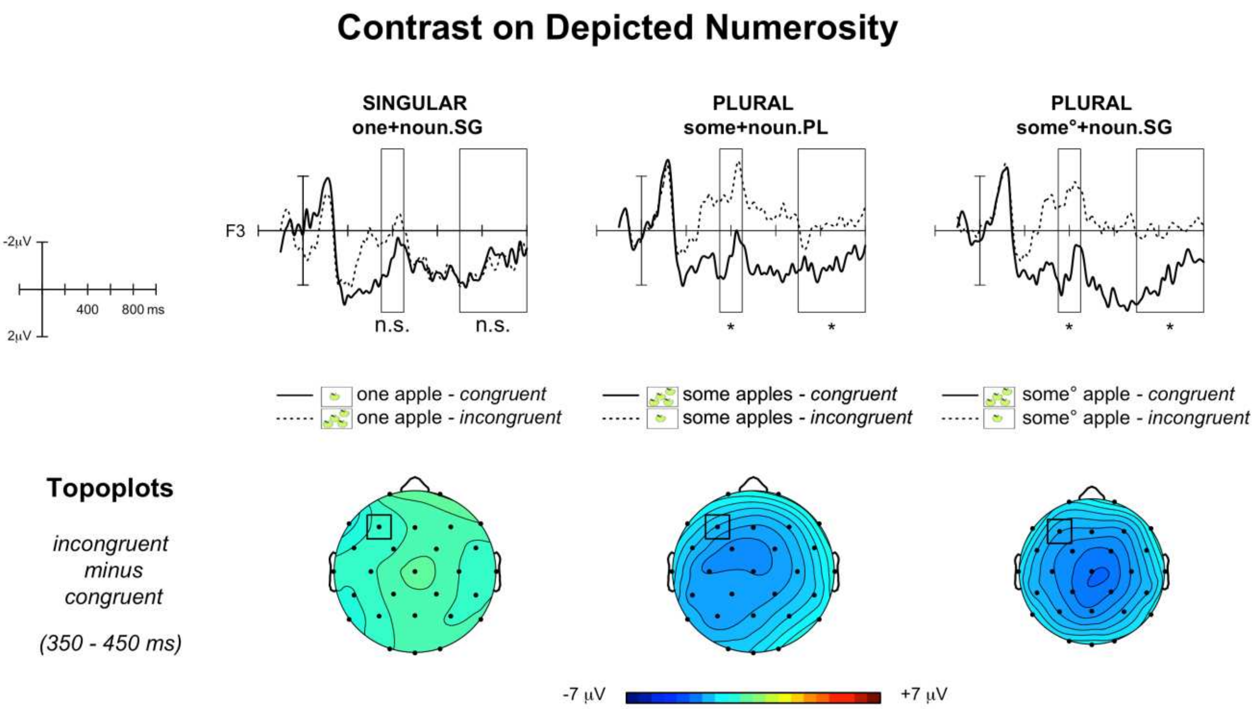


Figure 2. ERP waveforms and main results for the contrast on depicted numerosity. The figure shows the ERP waveforms on a representative electrode (F3) and the main results for the ANOVA analysis for the contrast on depicted numerosity. The upper panels show the waveforms for the three different quantifier (one+noun.SG, some+noun.PL, and some°+noun.SG). The square indicates the time windows used in the analysis and the asterisks indicate that the post-hoc comparing the effects in the time windows was significant. The bottom row displays topographic plots of the mean effect in the 350-450 ms time window, used to investigate early components. The small square indicates the electrode represented in the upper panels.

3.3.3. Contrast on depicted object, early time window (350-450)

In this analysis we found a significant effect of *Semantic F-Number* × *congruence* [$F(2,50) = 8.04$, $p < 0.001$, $\eta_G^2 = 0.05$]. Post-hocs of this interaction showed that when the depicted object was incongruent all *Semantic F-Number* showed more negative values as compared to congruent depicted objects [*ps* < 0.05]. Moreover, in the case of an incongruent object the semantic feature of the morphological Number in trials involving *one+noun.SG* had less negative values as compared to *some°+noun.SG* and *some+noun.PL* [*ps* < 0.05], which did not differ one from the other [$p = 0.86$].

3.3.4. Contrast on depicted object, late time window (700-1000)

In this time window no significant effect involving the experimental variable was found.

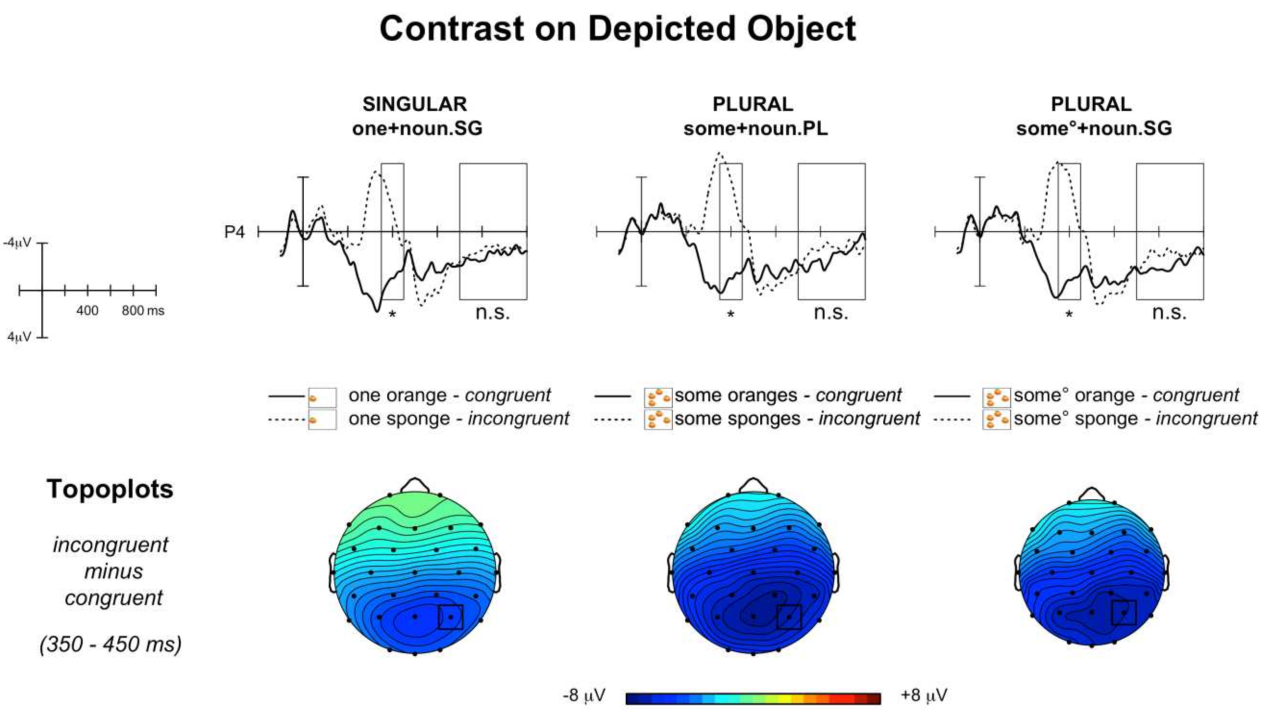


Figure 3. ERP waveforms and main results for the contrast on depicted object. The figure shows the ERP waveforms on a representative electrode (P4) and the main results for the ANOVA analysis for the contrast on depicted numerosity. The upper panels show the waveforms for the three different quantifier (one+noun.SG, some+noun.PL, and some°+noun.SG). The square indicates the time windows used in the analysis and the asterisks indicate that the post-hoc comparing the effects in the time windows was

significant. The bottom row displays topographic plots of the mean effect in the 350-450 ms time window, used to investigate early components. The small square indicates the electrode represented in the upper panels.

3.4. Mass Univariate Analysis

3.4.1. Morphological contrasts

Results of Mass univariate analysis are reported as raster plots in Figure 4 (for the contrast on depicted numerosity) and Figure 5 (for contrasts on depicted object). ERP waveforms for all electrodes and mass univariate results are also reported in the Supplemental Data.

In the contrast on depicted numerosity, the conditions in which the semantic feature of the morphological Number was interpretable as plural (*some°+noun.SG* and *some+noun.PL*) were characterised by significantly more negative amplitude in the incongruent condition (i.e. the figure with just one item) as compared to the congruent condition (i.e. the figure with four items). The effect was present in the timepoints associated with the early time window (350-450 ms) and in most electrodes was significant also in later timepoints. As for *one+noun.SG,* some significant effects were found, with more positive values for incongruent conditions as compared to the congruent ones in very early time windows (around 0-100 ms after the noun), in centroparietal electrodes. Results are reported in Figure 4.

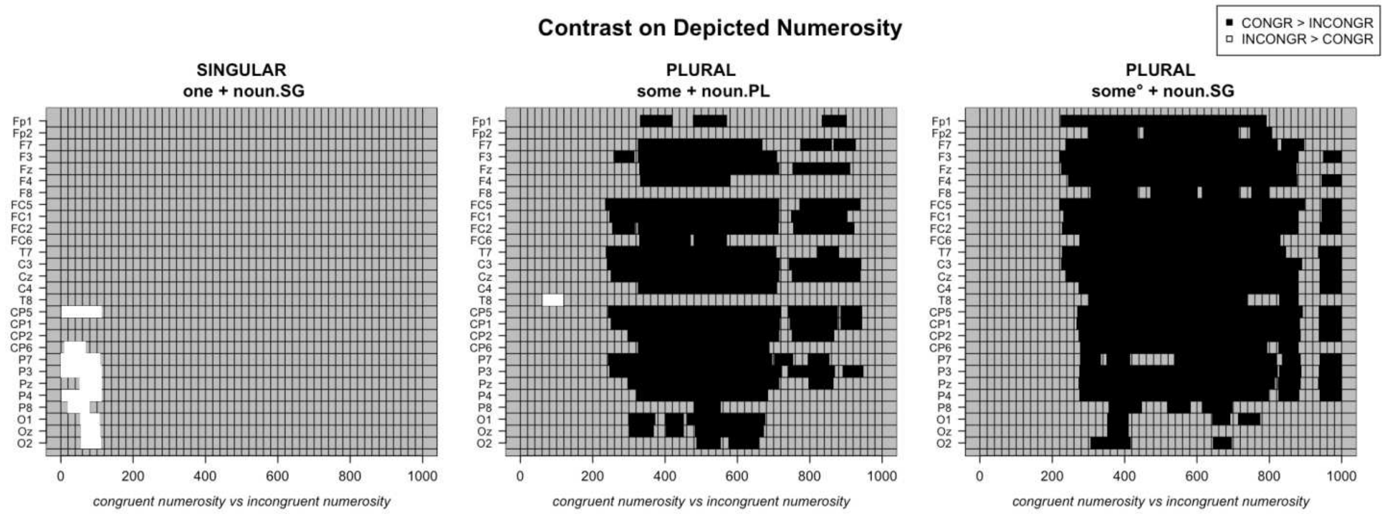


Figure 4. Results of Mass Univariate Statistics of Contrast on Depicted Numerosity. The figure shows, in the form of raster plots, the results of mass univariate statistics. In each raster, in the y-axis, each row represents one electrode and the x-axis represents the time. Each cell represents an interval of 10 ms. Grey rectangles denote intervals with no significant effect. Black or white rectangles denote significant effects. In particular, black rectangles indicate that incongruent had more negative values than congruent, while white rectangles indicate that incongruent had more positive values than congruent. Significant effects were calculated from paired t-tests, with p-values corrected with FDR method.

In the contrasts on the depicted object, the results showed a significant difference around 250-400 post stimulus, with more negative values for the incongruent conditions as compared to the congruent ones, especially in posterior electrodes. This difference was qualitatively similar in the three quantifier types, *one+noun.SG, some+noun.PL* and *some°+noun.SG*. The mass univariate analysis highlighted another later effect, at around 500-600 ms (comparable across the three quantifier types) with more positive values for incongruent as compared to congruent trials. This last effect was found mostly in left lateralized electrodes. Results are reported in Figure 5.

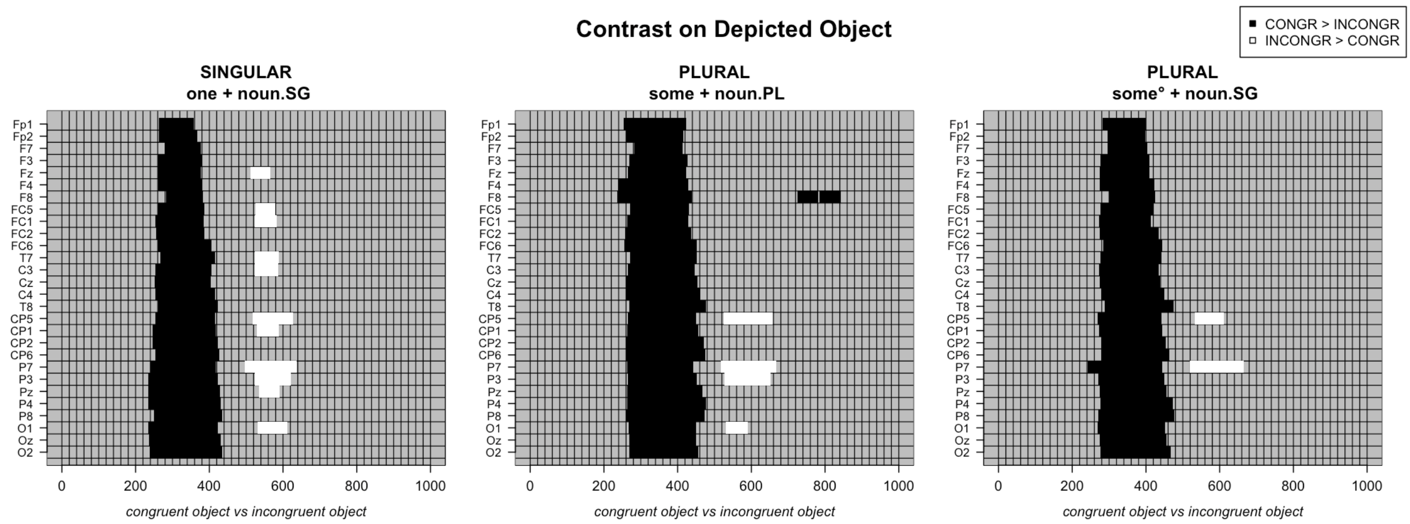


Figure 5. Results of Mass Univariate Statistics of Contrast on Depicted Object. The figure shows, in the form of raster plots, the results of mass univariate statistics. In each raster, in the y axis, each row represents one electrode and the x axis represents the time. Each cell represents an interval of 10 ms. Grey rectangles denote intervals with no significant effect. Black or white rectangles denote significant effects. In particular, black rectangles indicate that incongruent had more negative values than congruent, while white rectangles indicate that incongruent had more positive values than congruent. Significant effects were calculated from paired t-tests, with p-values corrected with FDR method.

4. Discussion

4.1 Morphological Number incongruence elicits LAN-like effects

Both ANOVA and mass univariate statistics converged in highlighting differences on the online processing of the experimental stimuli (i.e. *one+noun.SG, some+noun.PL,* and *some°+noun.SG).* As a first main result, the congruence between the number of objects in the picture and the semantic feature linked to the morphological Number of the following phrase modulated the amplitude of the ERPs in an early time window (350-450 ms), with more negative values in incongruent trials than in the congruent ones. This early component showed a topography compatible to that of a LAN in both plural conditions, although, according to both topographic representations and MASS univariate result it was more left lateralized for *some+noun.PL* and more central for *some°+noun.SG*. Differently from the typical LAN that is observed in studies with morpho-syntactic agreement violations, this component had a longer duration and entailed also the second analysed window (700-1000 ms), that was designed to capture the P600 (Molinaro et al., 2015). Probably, this long lasting negativity and the absence of a P600 effect are a consequence of the peculiarity of this task that did not employ any grammatical violation, but a mismatch between the referential numerosity and the morphological Number of the following phrase, and thus did not require any repair or re-analysis processes (DeLong, Quante, & Kutas, 2014, Friederici, 2004). Importantly, a difference between congruent and incongruent trials in this LAN-like component was not found in the case of *one+noun.SG.*

In the condition involving contrasts on the depicted object, a negative effect in similar time window was reported for incongruent trials (e.g. a picture of four oranges followed by the phrase *alcuni martelli* 'some hammers') as compared to the congruent ones (e.g. a picture of four oranges followed by the phrase *alcune arance* 'some oranges'). However, such negativity had a qualitatively different topography than the one observed in the condition involving contrasts on the depicted numerosity, being more posteriorly localized and thus better interpretable as an N400-like effect. Moreover, this effect was significant for all the phrases, independently from the morphological Number value of the nouns and the denoted numerosity (and only with a little difference for *one+noun.SG* condition), whereas the numerosity congruence effect was not observed for nouns inflected in the singular conveying a numerosity of one.

The mass univariate analysis confirmed the results of the ANOVA, indicating greater negativity only for incongruent condition in which the morphological Number is linked to a semantic feature of plurality, but also highlighted some additional results. Indeed, we found an increased positivity (left lateralized) after the N400-like effect in the condition involving the contrast on the depicted object. This effect could reflect a re-analysis after the detected incongruence in which there was a highly expected ending. This kind of situation typically elicits a so-called Semantic P600 (Bornkessel-Schlesewsky & Schlesewsky, 2008). This effect was not found in the ANOVA because of the different time windows that was selected (a-priori) for that analysis.

Crucially, the negativity found for the contrast on depicted numerosity cannot be explained by the neural correlates of generic expectations and predictions performed in the task, but rather it may reflect a more genuine effect of incongruence between the semantic feature of the morphological Number and the referential numerosity. This conclusion is supported both by the topography of the effect (similar to LAN) and by the differences in the early components found between the numerosity and the object conditions (the former more similar to a LAN, the latter more similar to an N400). If our interpretation is correct, we succeed in eliciting a LAN-like effect without exploiting a grammatical violation paradigm, but exploiting violations of a morphological Number value in relation to the referential numerosity. It follows that, assuming that the component we elicited is comparable to the LAN found in literature with grammatical violations, the LAN component can be considered not only an index of difficulties in integrating grammatical anomalies linked with the syntactic level such as agreement mismatches, but also reflecting difficulties in integrating mismatches between values of morphological features in phrase context and extra-linguistic referential features such as numerosity. The LAN has been mostly considered as an index of morpho-syntactic expectancy violation in the literature (e.g. Molinaro, Barber, & Carreiras, 2011). However, this is not only true if a linguistic word form does not covary with the relevant one as established by the morpho-syntactic rules (e.g. **I ragazzi.PL corre.SG* 'the boys runs'), but also if a linguistic word form is not strictly related to the pertinent referential information (i.e. the numerosity of the referent in this study).

Moreover, these results provide further evidence in favour of an independent LAN that can be triggered irrespectively of the P600 (e.g. Molinaro, Barber, Caffarra, & Carreiras, 2015).

On the one hand, such findings are consistent with models claiming for an early effect of the morphological features during language comprehension (e.g. Friederici, 1995; 2002). On the other hand, our data can support the view that morphological Number processing in phrase context is not blind to cognitive salient world features such as numerosity. In the literature it has been already claimed that morpho-syntactic processing can recruit lexical or discourse-level information to compute formal relationships between words in a sentence (Barber & Carreiras, 2003, 2005; Deutsch & Bentin, 2001; Mancini, Molinaro, Rizzi, & Carreiras, 2011; Molinaro, Vespignani, et al., 2011) Here we show that we count whenever we inflect words for morphological Number in phrase context.

4.2 Partial incremental effects of Number morphology

In the contrast on depicted numerosity, we found significant effects on ERP time-locked to the content noun. In our experimental design, the noun occurred after a first word (i.e. a quantifier) that was sufficient to signal the morpho-syntactic incongruence: if the quantifier was not congruent with the preceding picture, there was no need to further process the content noun, as the response to be provided was surely "false". Nevertheless, in correspondence to the content noun (except for the cases involving *one+noun.*SG) we did find a negativity associated with an incongruence effect. This result speaks against full incremental models, that would predict no need to detect incongruence with the second word (as the incongruence was already detected in the previous word). A full incremental model would not be able also to explain the difference of incongruence effect we found across the quantifiers (i.e., no significant effect of incongruence for *one+noun.SG*).
On the other hand, if Number morphology in phrase context was processed in a wait-and-see fashion, or if Number morphology was automatically accessed, we would have expected a different effect, with a bigger LAN in the trials involving *some°+noun.SG* preceded by a figure representing four items. In fact, in this case, the morphological Number value of singular of the second word considered alone is inconsistent with the numerosity depicted in the figure, and it is the presence of the quantifier *qualche* '°some', which allows to interpret it as a plural.
Differently from the prediction that could have been made from full incremental models or wait-and-see models, in the present experiment we found the incongruence effect when the phrases *some°+noun.SG* were preceded by figures depicting one item: in this case we observed a greater LAN-like component as compared to the cases in which the phrases *some°+noun.SG* were preceded by figures depicting four items. Thus, our results can best fit with models of partial incremental processing of language, in which gathered evidence is partially integrated with incoming material (K. a DeLong et al., 2005; Urbach & Kutas, 2010).
It could be argued that the incongruence effect on the morphological conditions found in the present experiment is the spillover effect from the anomaly of the quantifier. This is, at least in part, necessarily true, as the incongruence is not just between the figure and the single noun, but the figure and both the quantifier and the noun together, which convey the semantic feature of the morphological Number. The present experiment alone does not allow to disentangle whether the effect on the noun is just a spillover on the quantifier or the sum of an effect on the quantifier plus another effect on the noun. Similar spillover effects, associated with increased negativities, have been found in different experimental settings (see for example King & Kutas, 1995) and have been associated to increased working memory load. In the present experiment, however, we have little reasons to think that the effects are related only to working memory (see 4.4 Limitations).

4.3 On the differences in the processing of singular and plural

As pointed out in the review by Molinaro and colleagues (2011; see the introduction), usually in ERP studies dealing with agreement, the morphological Number values of singular and plural are collapsed together in the analyses. Here we contrasted these two Number values and found a difference in the ERP correlates between the processing of nouns inflected in the singular and in the plural. More precisely, an important result in our study concerns the absence of any incongruence effect in the experimental trials involving *one+noun.SG*, i.e. when the nouns were inflected in the singular bearing a numerosity equal to one. Differently, we did find incongruence effects when the nouns were inflected in the plural bearing a numerosity of plurality (*some+noun.PL*). We found incongruence effects even in the case in which the numerosity was not specified at the morpheme level, but -unambiguously- at the phrase level (*some°+noun.SG*). Hence, whenever a morphological Number value in the phrase context was linked to a numerosity greater than one and was preceded by a picture of one item, it elicited a LAN-like effect. On the contrary, when a morphological Number value was linked to numerosity equal to one and was preceded by a picture of four items, no LAN-like effect was observed.

A tentative explanation for such pattern may relay on the fact that plurality -when encoded into Number morphology in the phrase context- has a narrower interpretability than the singular. At a first glance, this can be surprising. And yet, a birds-eye-view of linguistic typology provides a more coherent picture. Besides singular and plural, many human languages can display other dedicated morphological Number values such as general, dual, trial, quadral, paucal, greater paucal, greater plural and collective. Interestingly enough, no language displays a Number system of ten values while most languages have a singular vs. plural system (e.g. Corbett, 2000). As a consequence, the information about numerosity that would be encoded in specific morphological Number values can be encoded into language with different means (e.g. lexically) or can be syncretically conveyed by the available values (Ackerman & Malouf, 2013; Carstairs, 1987; Loporcaro, 2011; Muller, 2007; Pirrelli & Battista, 2000; Stump, 1991; 2006; 2010). From a typological point of view, singular, more than plural, is prone to be the default unmarked morphological Number value and can often syncretically convey other values such as general Number (e.g. an underdetermination of the numerosity) or can even express uncountability in the case of mass expressions, as in Italian (e.g. *il mio pappagallo ha mangiato troppa mela* 'my parrot ate too much apple.SG'; for Italian see, among others, Acquaviva, 2013). Even if we constrained the interpretability of the morphological Number values in our experiment by means of the quantifiers (i.e. 'one, some, °some'), a difference still emerged along the lines shown in typology.

An alternative interpretation of the results we found may stem from the observation that a set containing many objects (in our case: four) always contains a set of one object as well, while the other way around is not true; This could explain why we found an early negative effect only when a morphological Number value in the phrase context was linked to a numerosity of plurality and was preceded by a picture of one object: only in this case there is a complete mismatch between the observed numerosity and the expressed morphological Number value. Following this reasoning, one could argue that at least from a semantic point of view it is not singular to be the unmarked value, but plural. Indeed, a line of research has claimed that plural nouns are semantically underspecified for Number since they can quantify over singular objects (Bale, Gagnon, & Khanjian, 2011; Krifka, 1989; Sauerland, 2008). For example, a question like "are there any English professors in the room?" can be answered affirmatively even if there is only one English professor in the room.

Although interesting, this kind of approach does not seem to fit properly our pattern of results at least for two reasons. Firstly, if it is true that plural nouns are semantically underspecified for Number we should *not* have observed a LAN-like effect when *some+noun.PL* (and *some°+noun.SG*) phrases were read after the picture of one object. Secondly, as explained in §4.1, we did not find any significant difference between singular and plural trials in the purely semantic condition involving contrasts on the depicted object (e.g. a picture of four oranges followed by the phrase *alcuni martelli* 'some hammers'). Taken together, these observations rather support a morphological explanation for the LAN-like effect we reported, suggesting that plurality at the phrase level is likely to receive a narrower interpretability than the singular.
Whatever the interpretation, the pattern of results we found is hardly reconcilable with a view of (Number) morphology as a strictly associative function between a form and a meaning. According to this perspective, in Italian the singular-plural opposition should mostly reflect the contrast of a referential numerosity of one vs. a referential numerosity different from one. If this was the case, we should have found a similar incongruence effect in the trials involving plural Number morphology as well as in the trials involving singular Number morphology. Instead, we found an incongruence effect only in the trials involving plurality at the phrase level. We propose here that there would be no actual contrast between a value denoting one and a value denoting numerosity different from one. Rather, the singular is more likely to be underspecified with respect to plural and thus this latter is more prone to receive a specific interpretation. This perspective is also consistent with recent findings on acquisition claiming for a discriminative morphological processing which should allow to separate systematically informative and predictive cues from less predictive ones with respect to a context (e.g. Ramscar, Dye, Blevins, & Baayen, 2015; Ramscar & Port, 2015; see also Rescorla, 1988).

Implications for theories on morphological processing

The majority of studies on morphological processing of written words assumes that complex words are early decomposed, and that this decomposition depends on the structural properties of the words (for a review see Amenta & Crepaldi, 2012). However which characteristics drive a morphological decomposition and what kind of information is accessed during processing is still a matter of debate (e.g., for a view that does not postulate a stage of morphological decomposition, see Baayen, Hendrix, & Marelli, 2011). An interesting perspective related to the issue of morphological processing is that posited by Norris (2006), according to which several effects observable in psycholinguistic tasks (not necessarily on morphology) can be explained assuming that we behave as "Bayesian Readers", making probabilistic choices that highly depend on the task goals. In particular, the "Bayesian Reader" theory is able to explain parsimoniously several inconsistencies found in the literature of masked priming and lexical decision (Kinoshita & Norris, 2012). This is of particular relevance for theories on morphological processing, as the large majority of studies on this topics comes indeed from experiments employing masked priming and lexical decision (Amenta & Crepaldi, 2012). Some interesting thoughts on this issue come from the study by Marelli and colleagues (Marelli, Amenta, Morone, & Crepaldi, 2013), who reports results from two experiments: using a lexical decision task, the authors were able to replicate the classical effects found in the literature (i.e., an early effect of morpho-orthographic decomposition based on word structure); however, the same results were not found in another experiment, in which eye movements were recorded and participants were required to perform a comprehension task. Thus, results by Marelli and collaborators suggest the importance of relying on different tasks and settings to address the issues of morphological decomposition.

Within this debate, most of the studies focused on derivational morphology or compounding, and relatively few studies investigated the effects inflectional morphology and the difference between singular/plural (but see for example Baayen, Dijkstra, & Schreuder, 1997). In the present paper we showed that, at least, for Number morphology, a phrasal context and a picture-phrase matching task may override the effects of Number value associated with the word taken in isolation: when the number Value of the two-word phrase used in the experiment was plural (even if the inflectional suffix of the word was singular), we found incongruence related ERPs, if the referential picture depicted only one object. Given the nature of the task and contrasts we used, we cannot fully disentangle whether and how this effect is related to a morphological decomposition of the inflected words; however, the topography of the effects (LAN-like) is traditionally associated to morpho-syntactic operations, and the latency of the effects is the same of to found in studies on decomposition in morphologically complex words (Koester, Gunter, & Wagner, 2007; Lavric, Clapp, & Rastle, 2007). Hence, it could be concluded that the operation performed in the current study is associated with some kind of morpho-syntactic processing on the single words. However, given the potential confound of a spillover effect (see § 4.4), further evidence is needed to corroborate this conclusion. Following Marelli et al., 2013, we think that to fully understand how number morphology processing unfolds over time, we need to rely on diversified tasks, measures, and settings, and not only on reaction times gathered from lexical decision studies.

4.4 Limitations

An important limitation of the present study concerns the interpretation of the effect of congruence in terms of a LAN. It may be argued that the difference in the congruent or incongruent trials is not necessarily a LAN, but another ERP component with different meaning, interpretation and neural generator.

For example, a first alternative explanation is that the effect reflects more positive values for congruent as compared to the incongruent trials; in other words, the difference would reflect a P300-like effect rather than a LAN (Polich, 2007). Another possible explanation is that the negativity is not actually a LAN, but rather a long-lasting negativity that reflects an additional processing possibly related to working memory (King & Kutas, 1995); this may arise in the presence of an incongruent quantifier and may be carried on the following noun as well. A third potential criticism is related to the distribution of the effect of our LAN-like components, that in the case of *one+noun.SG* was bilateral and not left lateralized. This result may suggest that the component we found does not actually resemble a LAN.

These explanations are intriguing possibilities that deserve to be further explored. Yet, we believe that even if the effects we found do not reflect a traditional LAN, this does not affect the relevance of the results. In fact, these more general accounts and explanations are hardly reconcilable with the absence of any incongruence effect in the trials involving the Number value of singular (*one+noun.SG*). Indeed, a generic effect of incongruence of working memory would not predict an interaction with a specific Number value in a specific context (which is the main result of the present study). Thus, it is likely that we managed to capture a specific effect of congruence between the depicted referential numerosity and the morphological Number value.

As for a long-lasting effect of incongruence on the quantifier, if this was the case, we would expect that the baseline correction should cancel out this difference. As the baseline correction procedure worked almost always we can reasonably conclude that a long-lasting effect cannot be the only explanation for the results we found. Time locking the ERPs to the noun was important to exclude any possible confound on more superficial characteristics of the quantifiers, which are intrinsically different (as for length or frequency) and to rule out several possible confounding explanations. Importantly, even if the effect of the noun is related to a spillover from the quantifier rather than a pure effect on the noun, this does not affect the interpretation of the results, which is indeed related not to the single noun, but to the phrase, composed by the quantifier and the noun.

Finally, although LAN is (by definition) left lateralized, several studies shows a bilateral distribution of LAN (e.g., Hagoort, Wassenaar, & Brown, 2003; Yamada & Neville, 2007; Ye, Luo, Friederici, & Zhou, 2006). However, the functional difference between these two different distributions is not known (Hahne & Friederici, 2002; Pakulak & Neville, 2010). As both the traditional LAN and our LAN-like components are just the electrode manifestation of underlying brain activities, a mere comparison in terms of spatial distribution of effects of electrodes is unreliable to infer neural generators (Urbach & Kutas, 2002, 2006). Rather, a more interesting and promising prospective to tackle this issue is to compare the LAN found in traditional morphological studies with the component found in the present experiment by using source reconstruction techniques in order to characterize the neural generators of the observed components. In this way it would be possible to trace back the difference in the brain regions recruited during the processing.

It is worth to make some considerations on the early component found in the Mass Univariate Statistics on one+noun.SG. In this condition we found an early positivity in some parietal electrodes, with more positive values for incongruent than for congruent condition. This effect was present in a very early time window (starting from 0). Given this early beginning it is likely that this component is a spurious effect related to a former component elicited by the First stimulus (the quantifier, see the Supplemental Data) and that could have affected the baseline correction time-locked to the Second word (the object) in the analyses. Crucially to our aims, this result does not affect the main conclusions of the present paper for two reasons: firstly, these effects were not found in the electrodes in which the LAN was obtained but in other electrodes; secondly, in the analysis on the early time window (350-450 ms) the value for *one+noun.SG* (both congruent and incongruent) was similar to the congruent condition for some+noun.PL and some+noun.SG. This suggests that for one+noun.SG there is actually no modulation for incongruence, a result that would be hardly reconcilable with a potential confound of the baseline correction. Future study varying inter-trial stimulus and with different stimuli (or different languages) are necessary to disentangle the meaning of this effect.

In a previous study by our research group (Gastaldon et al., 2016) we examined the RTs in a picture-sentence congruence task similar to the present one. In that task, quantifier and noun were displayed simultaneously and the participants were asked to respond whether picture and phrase were congruent or not as soon as possible. We found slower RTs for some°+noun.SG as compared to all other conditions, irrespective of congruence. This is in contrast with the results of the present study in which it was rather one+noun.SG that showed a different processing as compared to the other conditions. There are several reasons that could explain these different patterns. A first one is purely methodological: as in the Gastaldon et al. (2016) task the dependent variable were the RTs to a decision, it is possible that we found more strategic aspects that were associated with the response strategy rather than a genuine linguistic process. The fact that we did not find an interaction with congruence could indeed support this conclusion. Additionally, in the behavioural study as both words were presented simultaneously it was not possible to disentangle the source of the effect (the quantifier, the noun, or both). The second one is related to the different processing opportunities that each task entailed: if the whole sequence is available, this could favour a holistic processing of both words, that was not possible in the current ERP study (in which words were presented in a word-by-word fashion). We argue that only an eye-tracking study could disentangle this issue, investigating the effect of landing position (that could allow a processing only of the quantifier or of both the quantifier and the noun) on the reading times of the quantifier-noun phrase.

5. Conclusions

In this study we investigated the ERP correlates of incongruence between the depicted numerosity and phrases. In particular, we focused on the difference between singular and plural. We showed that numerical representation is to some extent accessed during Number morphological processing since incongruence between the referential numerosity and the semantic feature linked to the morphological Number value elicited a negativity that we interpreted as a LAN-like effect, even in the absence of a proper morpho-syntactic violation. This result can further support the view of the LAN component as an index of a genuine morphological processing irrespective the grammaticality of the utterances.

We hypothesise that if Number morphology and its processing can reflect cognitive salient information about numerosity, they do so in a non-strictly-associative fashion. In fact, we failed to observe significant incongruence effects in trials involving the morphological Number value of singular. Since a LAN-like effect was found only in trials involving plurality at the phrase level, we suggested that this latter has a narrower interpretability than the singular. Singular is the default unmarked value not only in Italian, but in the great majority of the world languages, it cannot be strictly associated to a numerosity equal to one irrespectively of the communicative context, and can express unspecified numerosity as well as uncountability.

In conclusion, this paper raises several questions that could stimulate further research in the field. Can the pattern of results be replicated in languages with the same Number system of Italian, i.e. singular vs. plural? Can this pattern be differently modulated in languages with other Number systems such as singular-plural-dual or general-singular-plural? If Number morphology reflects salient core knowledge information, what about other morphological features such as Gender? More generally, does inflectional morphology reflect salient information represented by the core knowledge systems? Mostly, these questions will benefit from further investigation on typologically different languages.

Authors contribution

Study Design: CZ, FF, GA. Pilot studies and stimuli selection: GA, SG, SB. Data collection and EEG pre-processing: GA, SG, SB. Statistical analysis: GA. Manuscript Preparation: GA, CZ, FF. Scientific Supervision on all steps: FP, CS. All authors provided feedback on the draft and approved the final version of the manuscript.

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